real time
collaboration and sharing

National Science Foundation Industry/University Cooperative Research Center
for e-Design: IT-Enabled Design and Realization of Engineered Products and Systems

Virtual Assembly Analysis and Simulation in an e-Design and Realization Environment

By
Bart O. Nnaji, Ph. D.
William Kepler Whiteford Professor and Director
and
Kyoung-Yun Kim, Ph. D.
Research Assistant Professor

NSF Center for e-Design and Realization
University of Pittsburgh
Pittsburgh, PA 15261, USA

University of Pittsburgh

Objective of Presentation

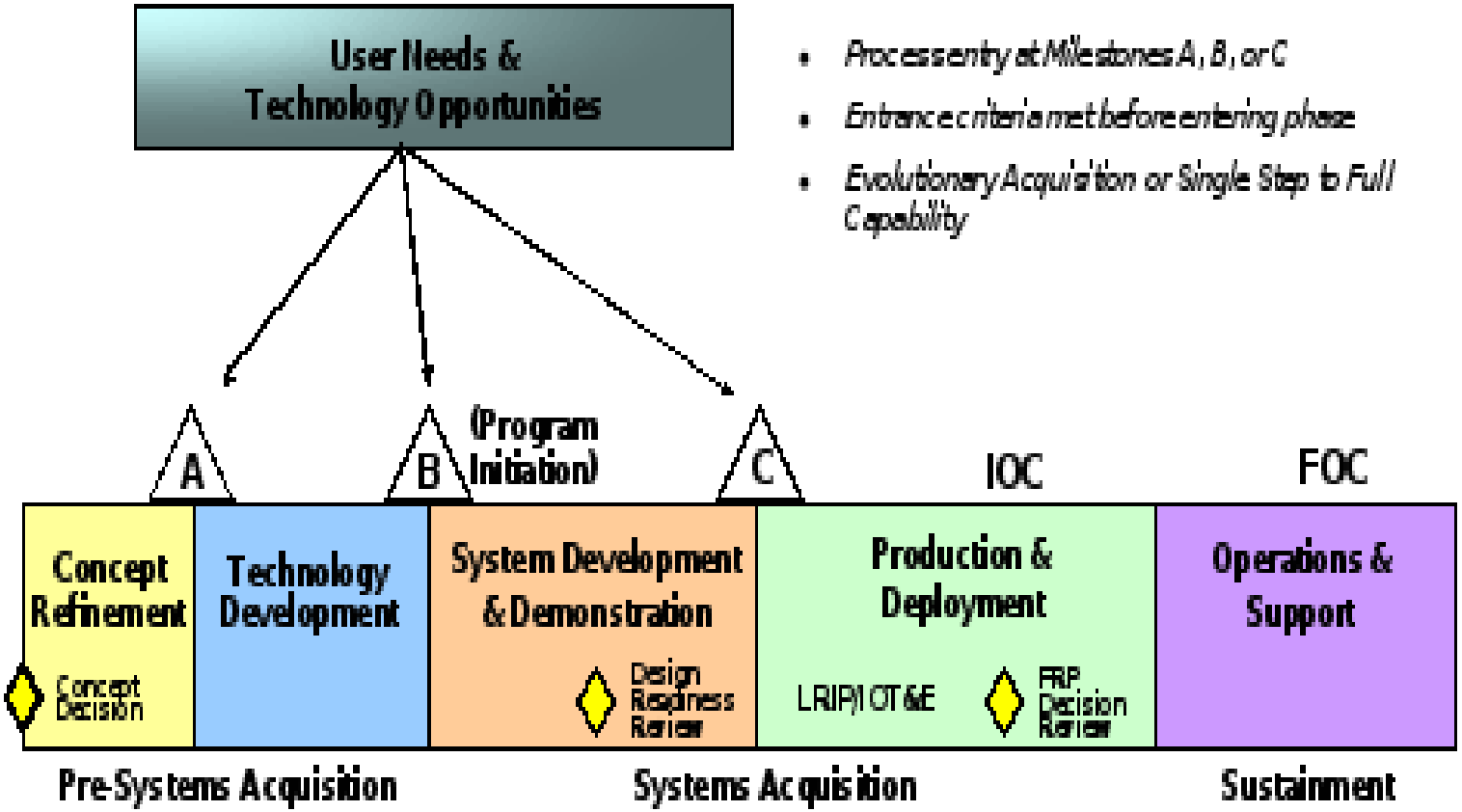
CENTER FOR e-DESIGN

- To show how an *e*-Design system can provide synergy tools for efficient implementation of the new DoD acquisition process

© Copyright 2002-

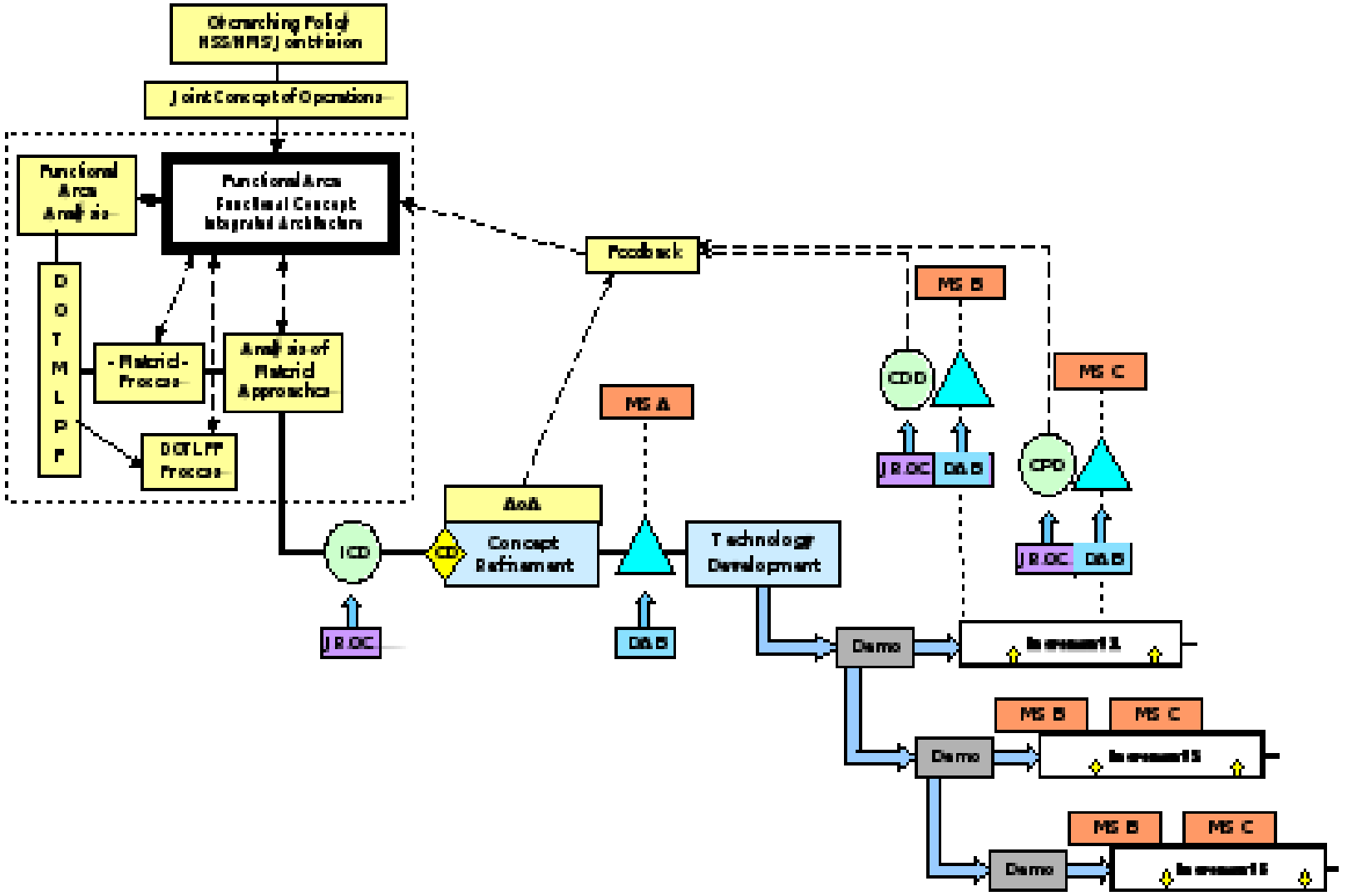
Defense Acquisition Management Framework

CENTER FOR e-DESIGN



© Copyright 2002-

DoD New Requirements and Acquisition Process – 3170 and 5000 Regulations



© Copyright 2002-

Integrated Architecture

CENTER FOR e-DESIGN

Operational	Desired function and how to achieve it
Systems	System to use to achieve it. How do systems interrelate?
Technical	What standards apply?

© Copyright 2002-

New Acquisition Process and e-Design System

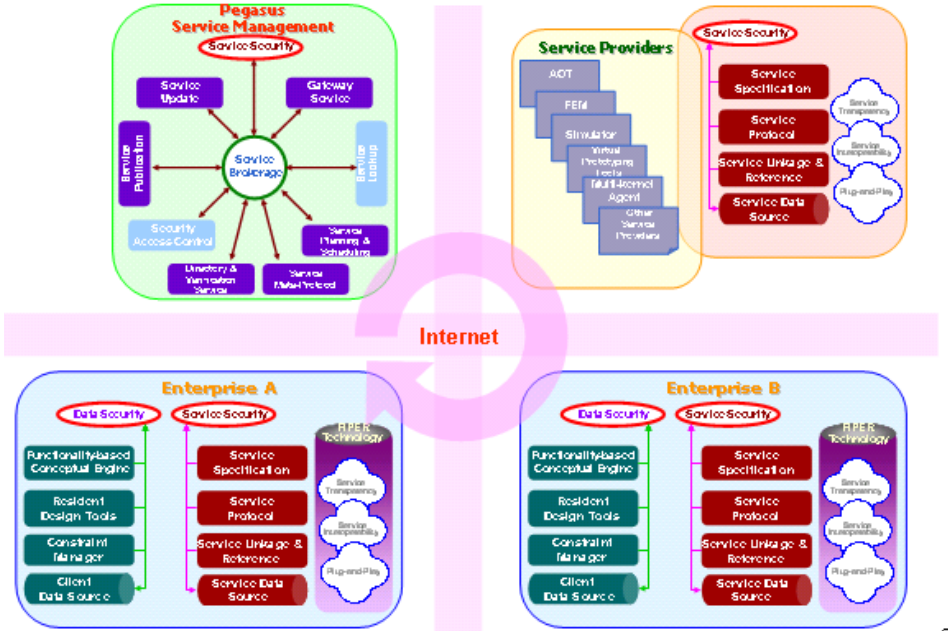
CENTER FOR e-DESIGN

Operational

Systems

Technical

e-Design System Architecture



© Copyright 2002-

NSF Center for e-Design Center Motivation

CENTER FOR e-DESIGN

- Discrete mechanical products:
  - $1 trillion in U.S. revenues per year
- Faster and cost effective product acquisition
- E.g. Automotive design cycle now 36 – 48 months:
  - needs to be 18 – 24 months and eventually 12 months
- More than 75% of product's acquisition costs committed at design time
- Industry needs to respond quickly with cost effective high quality products
- Industry can achieve this by evolving a faster, more efficient product design and realization paradigm
- Internet-based design studio can significantly reduce costs
- Current design collaboration requires efficient workgroup interaction. Effort should be applied to product development and not collaboration tasks (e.g., scheduling meetings, documentation, etc.).

© Copyright 2002-

Industry Technology Needs

- New paradigm in design of engineered products: ***systems approach***
- Interoperability among heterogeneous systems
- Customer-oriented and supplier communication
- Collaboration among all stakeholders
- Remote and distributed design via Internet → "online collaboration"
- Design information/knowledge sharing among all collaborators
- From concept to form
- Direct constraint imposition
- Multidisciplinary constraints
- Scalable, flexible and efficient platform
- **Virtual product prototyping with Physical laws realization**

CENTER FOR e-DESIGN

© Copyright 2002-

Implementation of New Acquisition Process uses Global Information Grid (GIG)

CENTER FOR e-DESIGN

Global Information Grid (GIG)

- GIG supports DoD missions with IT for national security, joint operations, e
- GIG shall be planned, resourced, acquired, following DoD 5000 regulations
- GIG assets shall be interoperable, followin approved requirements, and compliant with operational system and technical vie
- GIG shall be based on a common, or enterprise-level, communications and computing architecture, etc.
- GIG plans, architectures, designs, hardwa shall support applicable levels to ensure security, management, etc.

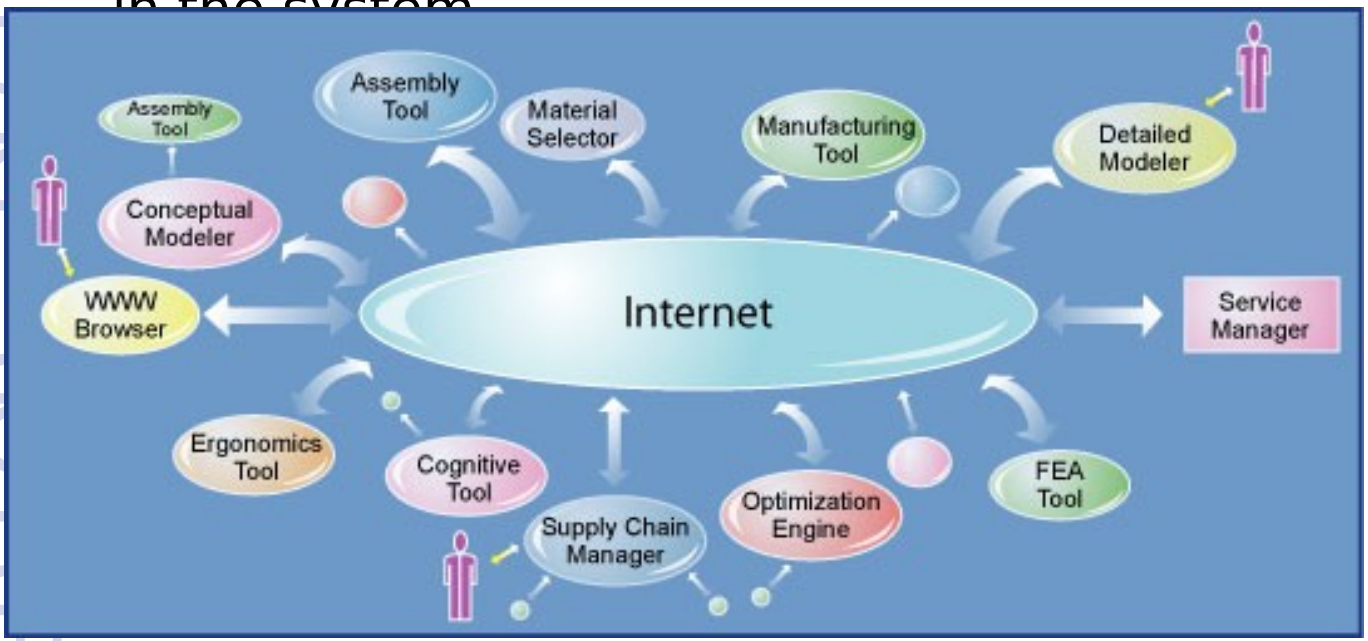
e-Design Service Architecture

E-Design system uses Internet-based service-oriented architecture for design realizatio of products and systems

© Copyright 2002-

Service-oriented Product Design and Realization and System Architecture

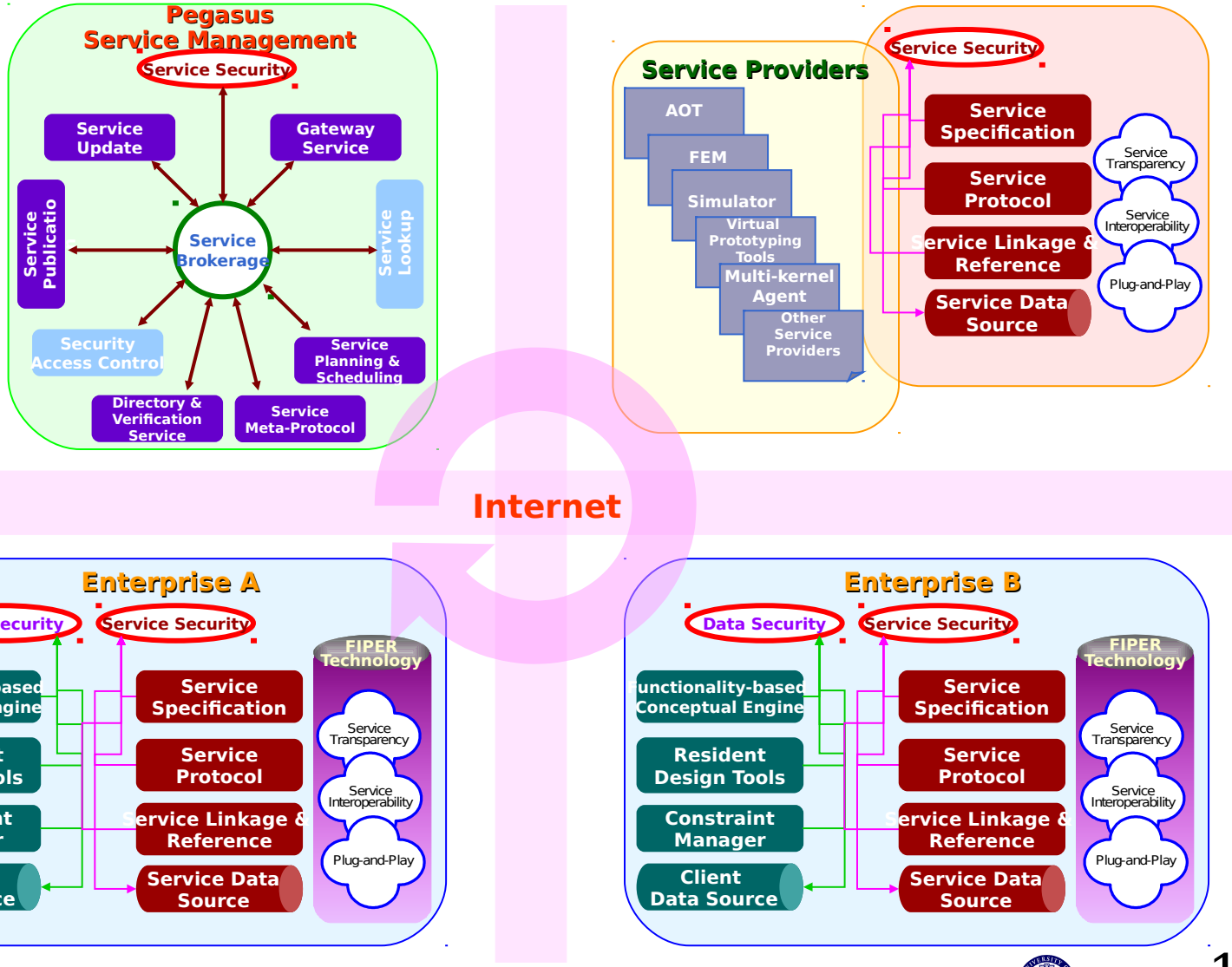
❖***Service*** is defined as a process that provides a functional use for a person, an application program, or another service in the system



- Compatibility
- Portability
- Scalability
- Extensibility
- Interoperability

© Copyright 2002-

e-Design Information Infrastructure



© Copyright 2002-

Illustration of Integrated Use of e-Design

CENTER FOR e-DESIGN

- New paradigm in design of engineered products: ***systems approach***
- Interoperability among heterogeneous systems
- Customer-oriented and supplier communication
- Collaboration among all stakeholders
- Remote and distributed design via Internet → "online collaboration"
- Design information/knowledge sharing among all collaborators
- From concept to form
- Direct constraint imposition
- Multidisciplinary constraints
- Scalable, flexible and efficient platform
- **Virtual product prototyping with Physical laws realization**

© Copyright 2002-

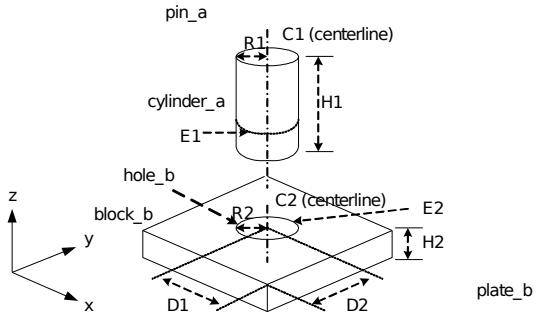
Needs of Assembly Design in e-Design

- Differentiation of assembly designs with different joints, such as weld joints and glue joints
- Assembly design persistently capturing assembly/joining relations during design collaboration
- Remote and transparent virtual simulation and testing to predict physical effects of joining in service-oriented architecture
- Shared understanding of assembly design intent and implications during design collaboration

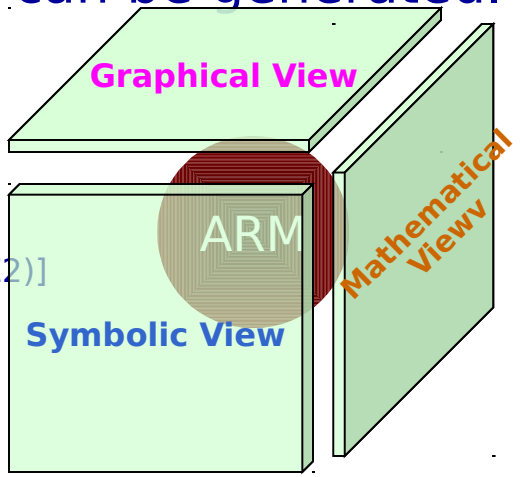
CENTER FOR e-DESIGN

© Copyright 2002-

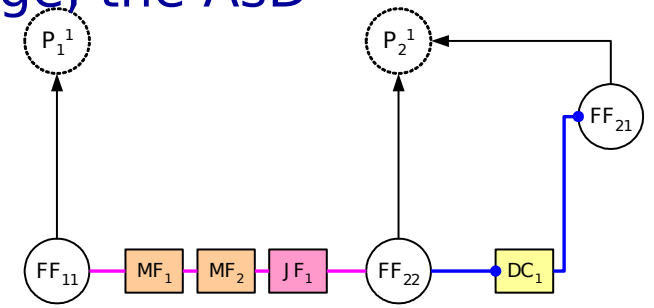
Assembly Design (AsD) Mo



- Capturing assembly and joining information persistently for assembly design collaboration.
- Consisted of **Solid Model** (SM) and **Assembly Relation Model** (ARM).
- ARM can be transformed into three views
  - symbolic view, mathematical view, and graphical view.
- All geometric entities in ARM are linked to a related SM.
- For lean assembly design data exchange, the AsD model's XML data can be generated.



{GMAW | single fillet | [FF11 (E1), FF22 (E2)]
| [welding_condition], [fixture_location]}

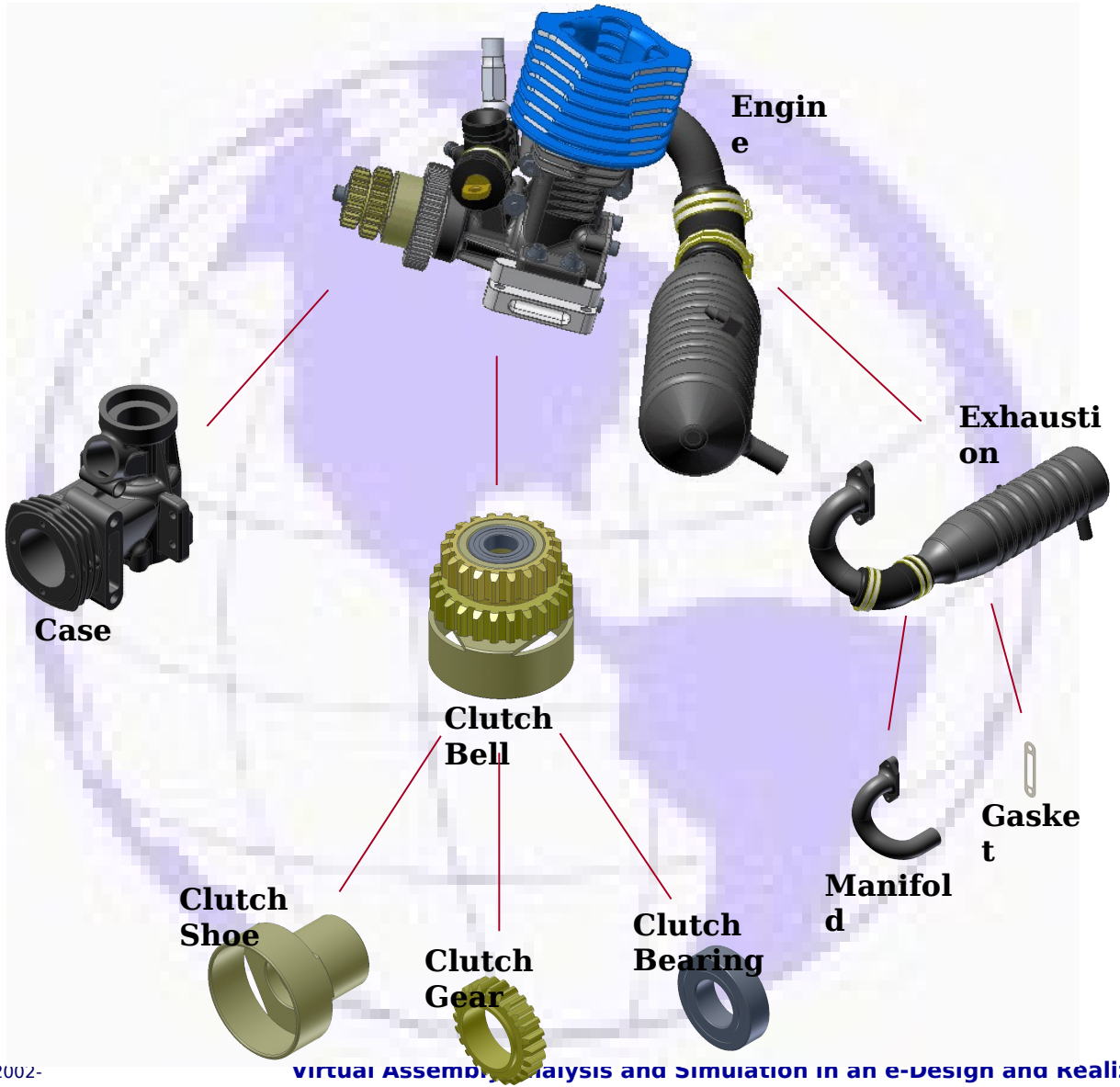


{FF11 :→ P11; FF21 :→ P21; FF22 :→ P21; FF21 ⇔ FF22 | RC12 = 0; FF11 ⊗ FF22;
IDI12(2) = {1}, JMI12(12) = {1, 2}, JJI12(12) = {1}, JDI12(12) = {0}}

© Copyright 2002-

Lean Information Sharing

CENTER FOR e-DESIGN

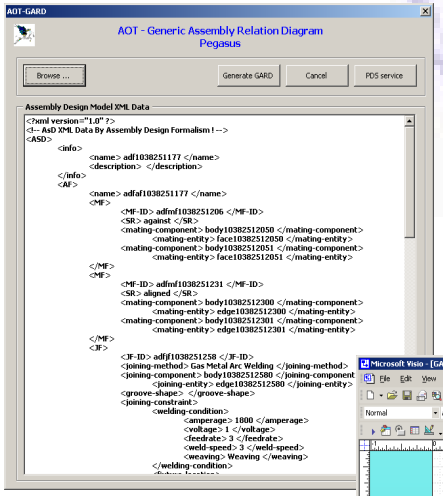


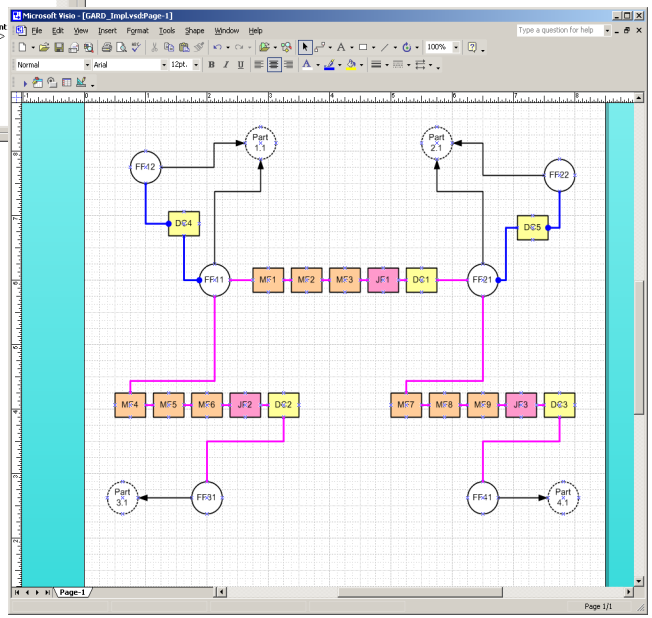
© Copyright 2002-

Selective Lean Information Exchange in Assembly Design

National Science Foundation Industry/University Cooperative Research Center for e-Design

- To overcome the bandwidth limitations on Internet/Intranet
- To achieve secured relationships among participants
- To monitor design changes and variations
- An AsD model captures persistently assembly engineering relations during this selective transition



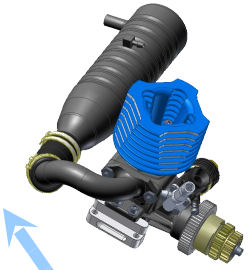


© Copyright 2002-

Assembly Design in *e*-Design Environment

National Science Foundation Industry/University Cooperative Research Center for e-Design

CENTER FOR e-DESIGN



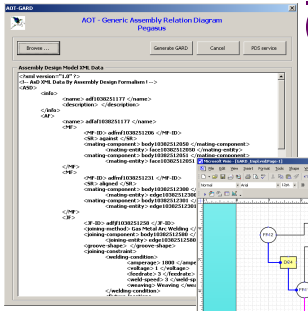
Analysis Service Providers e.g., ANSYS

Pegasus Multi-Kernel Agent

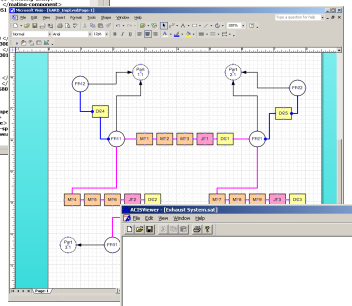
ARM/SM

e-Designer

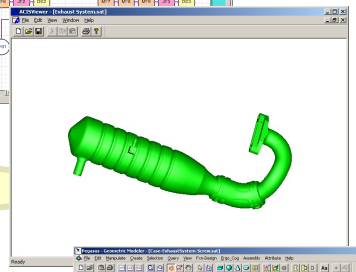
System Integrator
e.g., Auto-manufacturer
(Automobile diesel engine)



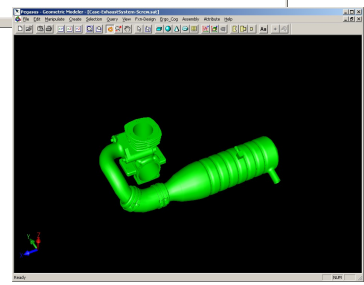
③



④



⑥



⑦

② ① ⑤ ⑧

Pegasus Service Manager

② ① ⑤ ⑧ ⑧ ⑤ ①

e-

Vendor 1
e.g., Auto-supplier
(Engine case)

SM

- CAD Model
- CAD Kernel Model

e-

Vendor 2
e.g., Auto-supplier
(Exhaust system)

SM

- CAD Model
- CAD Kernel Model

 # Index of processes

Assembly Implication and Virtual Assembly Analysis (VAA)

CENTER FOR e-DESIGN

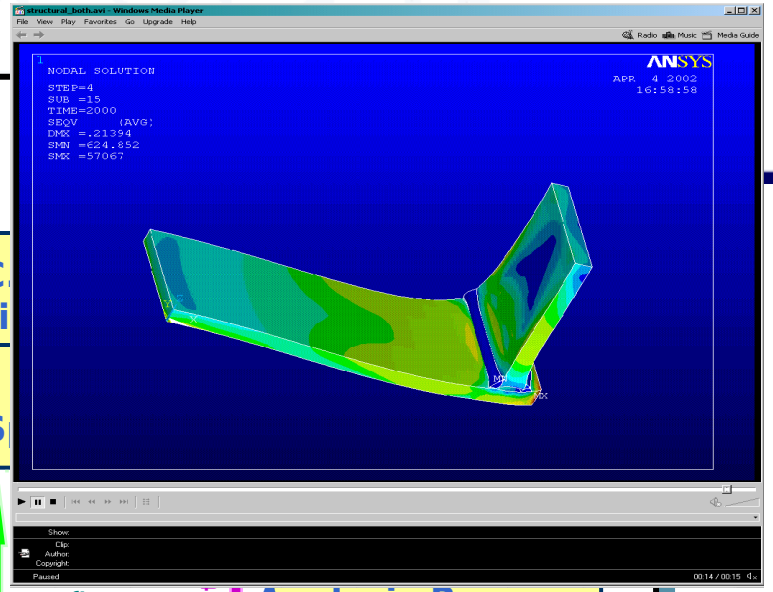
- Prediction of various effects corresponding to specified joining process in up-front design is very critical to understand the performance of assembly design
- Transparent and remote virtual simulation and testing on joining
- Natural collaboration of design tools and analysis tools
- Equal understanding of assembly design implications during design collaboration
- A set of joining process implications (i.e., riveting and arc welding) are developed as a framework.
- A third party analysis tool, such as ANSYS, is used as the assembly analysis service provider
- Assembly Implications
  - Physical effects
  - Spatial relationship implication
- The assembly implication engine including VAA embedded into assembly design process, captures various implication information.

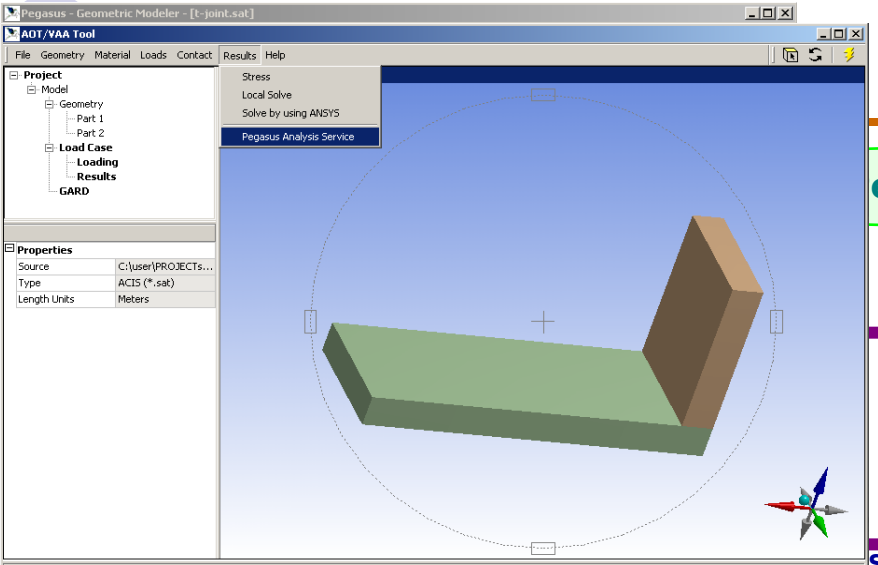
© Copyright 2002-

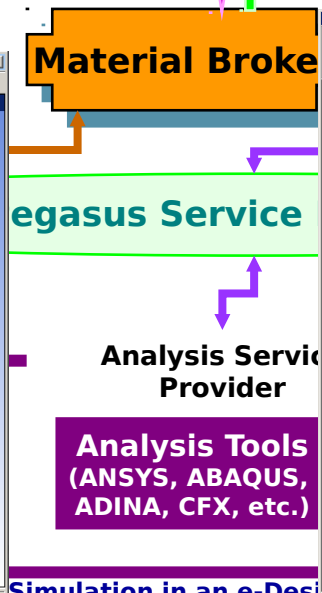
VAA Tool

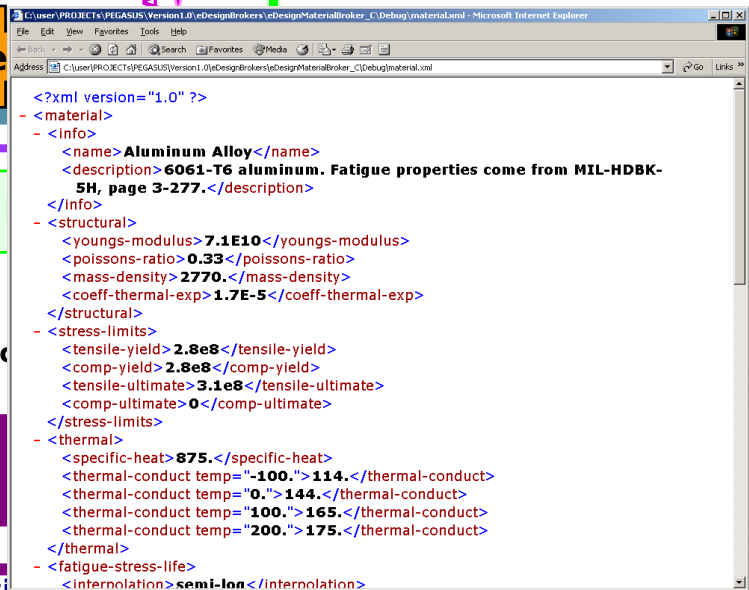
National Science Foundation Industry/University Cooperative Research Cen

e-DESIGN

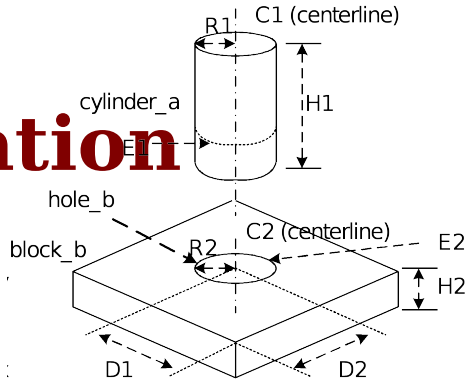


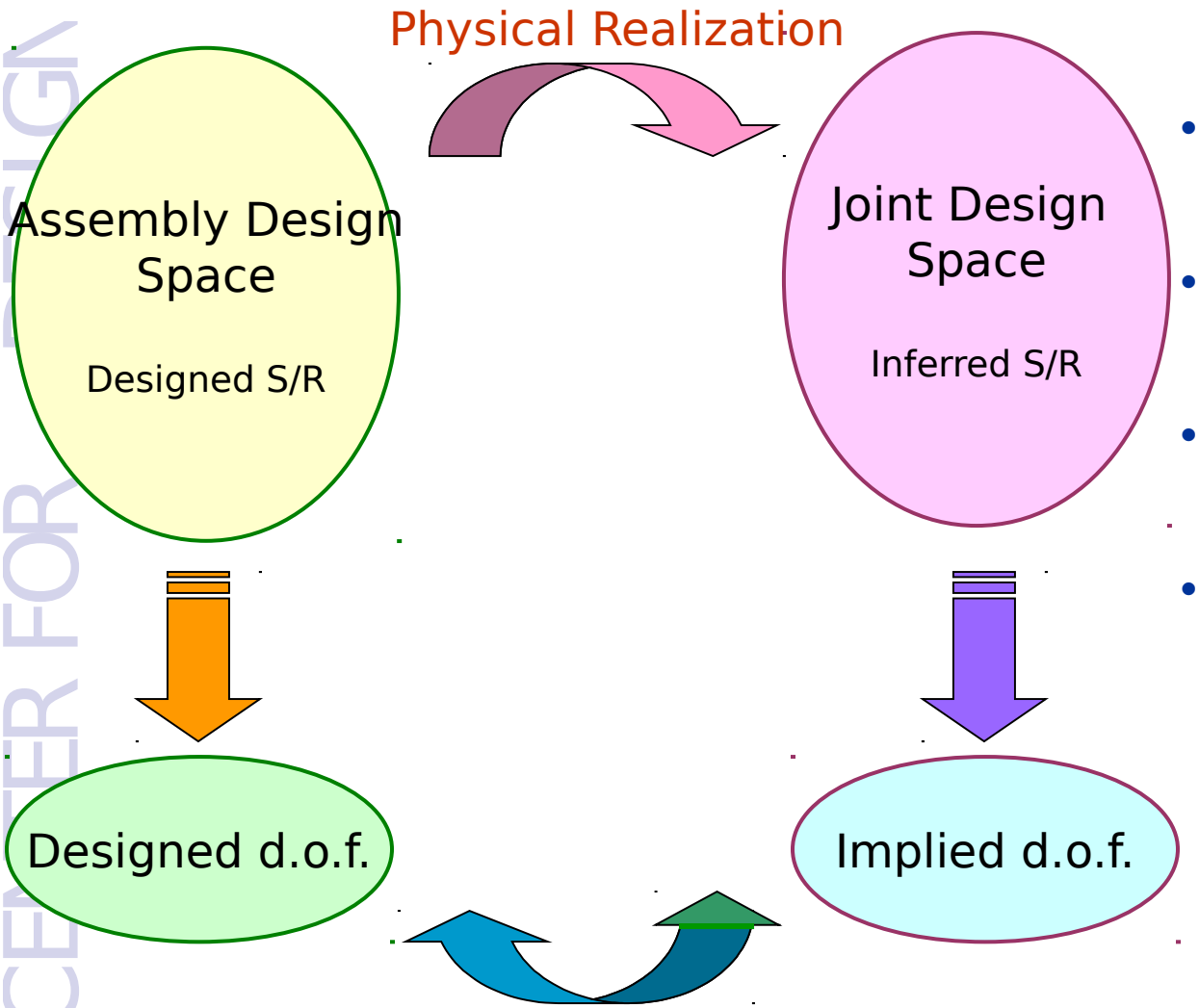






Spatial Relationship Implication



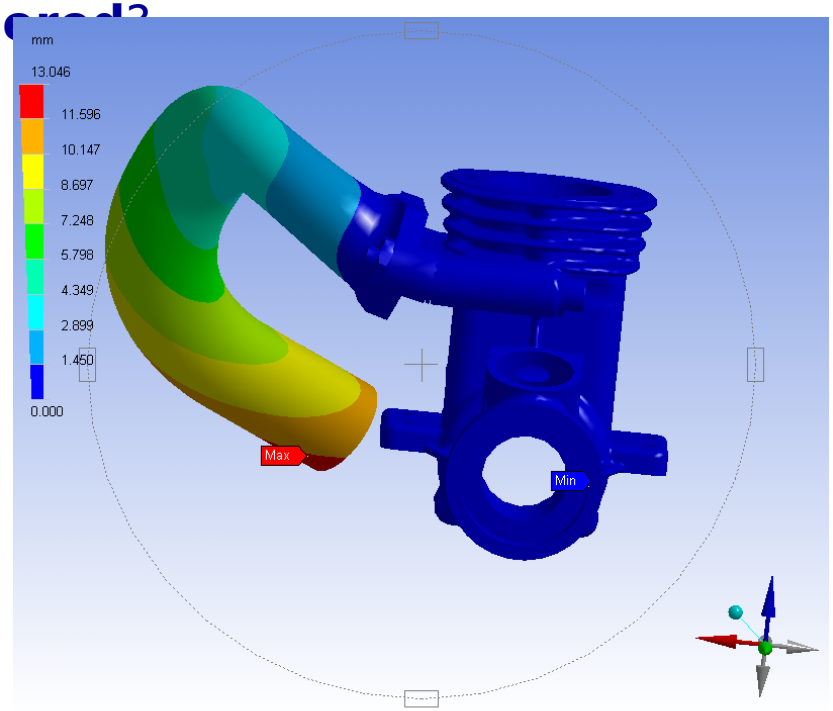


- Each S/R can be interpreted as a constraint imposed on the d.o.f. between relative mating or interacting features
- Any allowable motion for parts has to follow a path along the directions specified by the d.o.f. in order to maintain their S/R.
- The designed S/R are realized and maintained (or enforced) in the physical assembly by joining
- In this manner, all collaborative design participants can have an equal understanding of design intent on assembly.

© Copyright 2002-

Assembly Design Decision (ADD) Problem

- ADD problem:
  - When a problem on the current assembly design is indicated, a designer should make a decision **whether to accept the current joint or modify it**. If the joint should be modified, then **should the current joining method be controlled or another joining method considered?**



CENTER FOR e-DESIGN

© Copyright 2002-

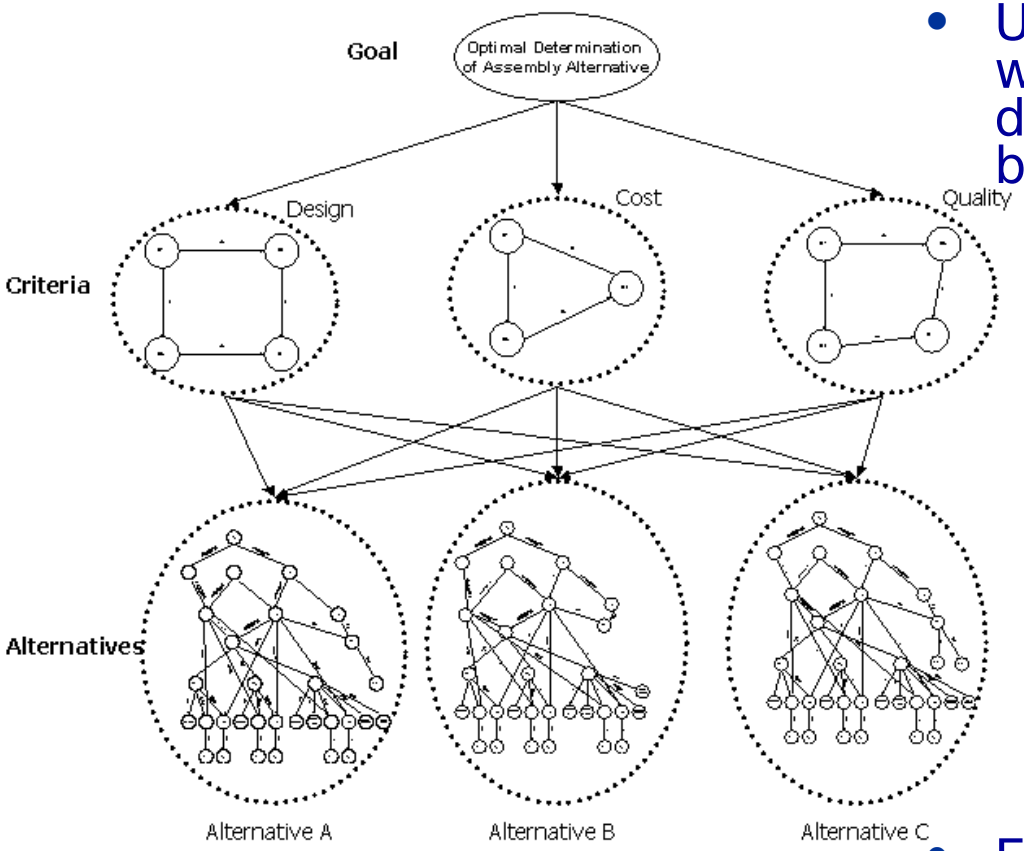
Assembly Design Decision Making (ADDM)

CENTER FOR e-DESIGN

- To propose AsD alternatives to the designer by considering AsD information, obtained from the AsD and AsI engines, and assembly/joining knowledge.
- A hierarchical semantic net (HSN) model is introduced as a core model **to represent evaluation knowledge and AsD knowledge, which is inevitable in knowledge based design decision making like ADDM**.
- Analytic Hierarchy Process (AHP) model
  - In general, the ADD problem is a multicriteria decision making problem. AHP is known as one of the well-received multicriteria evaluation methods.
- However, since the ADD problem is **in nature knowledge-intensive**, the typical AHP model lacks knowledge representation power.
- Hence, semantic net is employed **to represent AsD and evaluation knowledge of AsD alternatives** of the AHP model.
- **HSN model**
  - The semantic net is embedded in the alternative, which is a component of the AHP model.

© Copyright 2002-

Hierarchical Semantic Net (HSN) Model



- Unlike a typical AHP, the weights of criteria can be determined by external rule bases or users.
  - e.g., if the demand for the product is high, the cost criterion will have relatively low weight in comparison to other weights.
  - e.g., if the financial situation of the company is weak and the company is willing to reduce cost, then the cost criterion will have a high weight.
  - Rules can be built based upon domain experts' knowledge.
- Evaluation values of each design alternative are determined from inner knowledge of each criterion.

CENTER FOR e-DESIGN

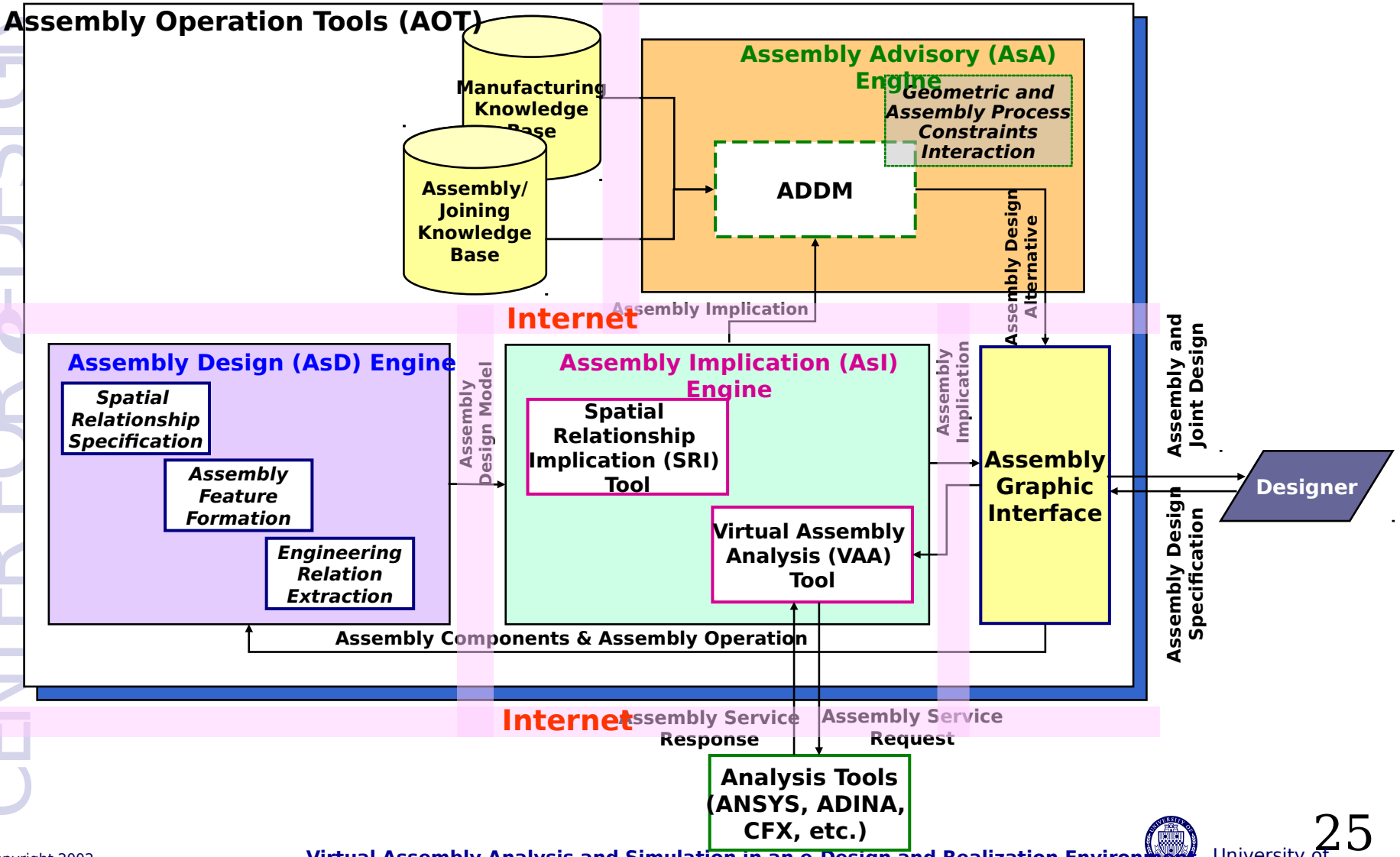
HSN and e-Design

- Utilizes distributed decision analysis models and design evaluation knowledge in enterprise-wide and world-wide collaboration
- To monitor and evaluate design changes and variations
- The assembly design knowledge captured from design collaboration can be seamlessly transformed into an AHP-hierarchy (HSN) for ADDM.
- Provide an environment that design collaborators can impose their constraints/specifications on the ADDM using AHP.
- The ADDM can manage interactions between alternatives and also between criteria.
- Allows independence between evaluation knowledge and design knowledge
  - The addition of new criterion or decision models will not affect the evaluation of design alternatives. It also enables the ADDM system to be scalable and extendable.

CENTER FOR e-DESIGN

© Copyright 2002-

Overall Architecture of AOT



CENTER FOR e-DESIGN

© Copyright 2002-

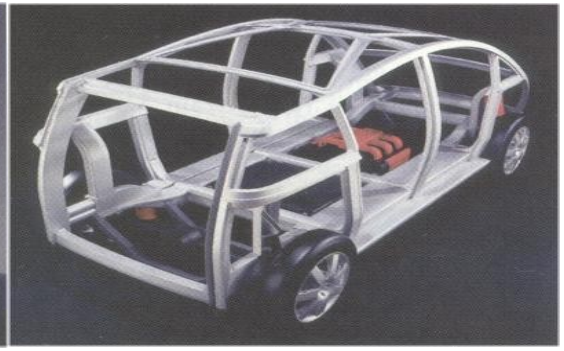
Demonstration

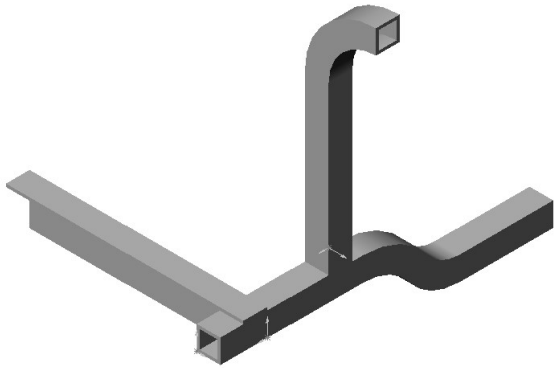
CENTER FOR e-DESIGN

- Demonstrated using a case study:
  - The design of a base sub-assembly of an automotive space-frame.
- This case study is based on given design specifications
  - i.e., maximum allowable stress and deformation
- The developed VAA method can predict potential AsD problems and can provide design/engineering information to improve the current AsD (that does not meet the assembly specification).

© Copyright 2002-

Assembly Design of an Automotive Space-Frame Sub-Assembly





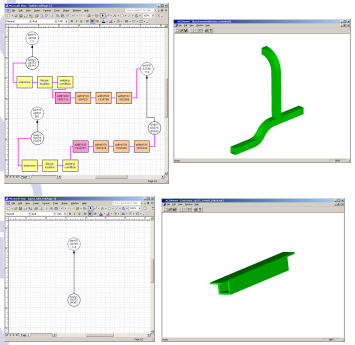
- Recent emphasis on lightweight environmentally sound car design (Buchholz 1999)
- An aluminum space frame assembly for an automobile
- Made up of aluminum beams with rectangular sections

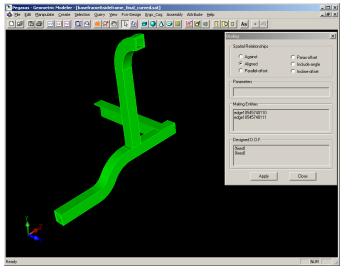
© Copyright 2002-

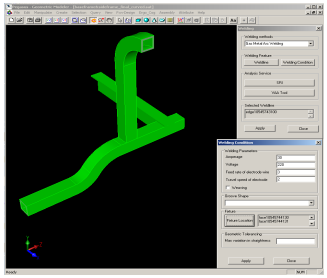
Assembly Design Processes

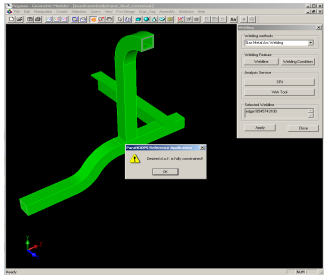
CENTER FOR E-DESIGN

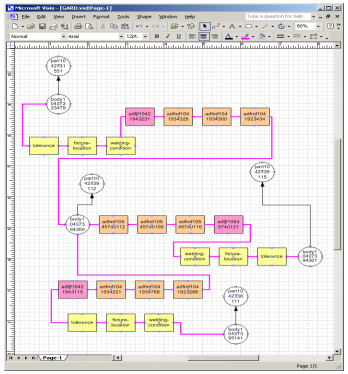
Product Data Sharing → **Spatial Relationship Specification** → **Joining Method Specification** → **F/R Implication Validation** → **AsD Model Generation**









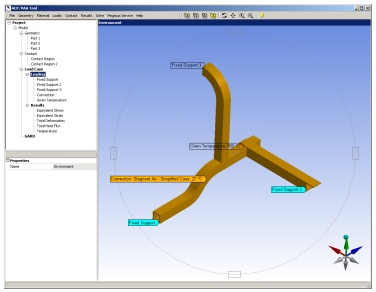


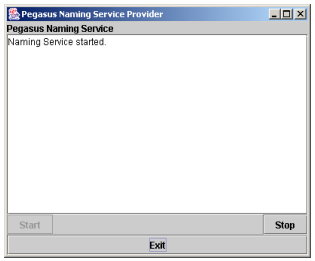
© Copyright 2002-

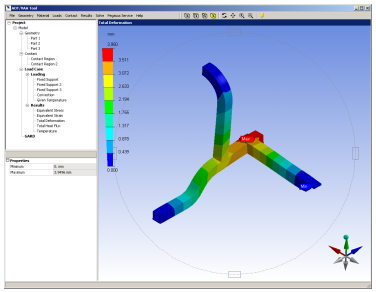
VAA Processes

CENTER FOR e-DESIGN

AsAM Generation → VAA Request → VAA Result Display





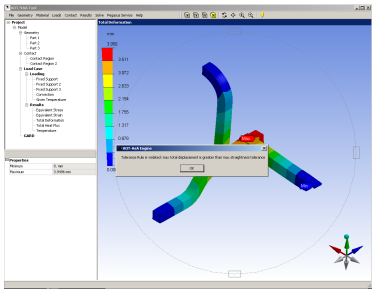


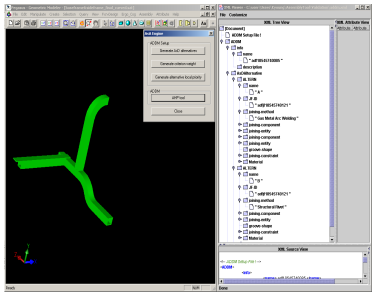
© Copyright 2002-

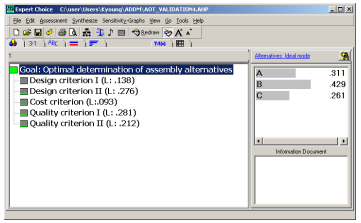
ADDM Processes

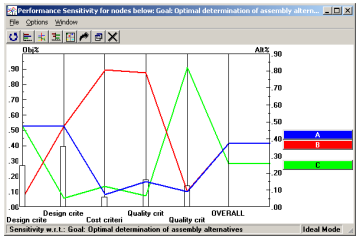
CENTER FOR e-DESIGN

Assembly Problem Indication → **AsD Alternative Generation** → **AHP** → **Sensitivity Analysis**









© Copyright 2002-

Industry Benefits: AOT Capability vs. Existing Commercial CAD Systems

Comparison Measure	Commercial CAD systems				Assembly Operation Tools
	AutoCAD	**SolidWorks**	**Pro/Engineer**	**CATIA**	
Assembly/joining relation capture	Not available	Limited support	Limited support	Limited support	**Supported**
Lean assembly/joining information exchange	Not available	Limited support (SMARTEAM as PDM solution)	Limited support (Winchill CAD Integrations as PDM solution)	Limited support (ENOVIA as PDM solution)	**Supported (through GARD and XML data)**
Designer's intent analysis on SRI	Not available	Not available	Not available	Not available	**Supported**
Transparent and remote analysis	Not available	Limited support (COSMOS/Works provides locally integrated analysis)	Limited support (Pro/Engineer Simulation software provides locally integrated analysis)	Limited support (TAA Workbench provides locally integrated analysis)	**Supported**
Assembly/joining knowledge capture	Not available	Not available	Not available	Not available	**Supported**
Assembly design decision support	Not available	Not available	Not available	Not available	**Supported**

CENTER FOR e-DESIGN

© Copyright 2002-

Conclusions

- This presentation illustrates that the new DoD acquisition process can be realized by employing *e*-Design tools
- System approach advocated in the new acquisition process guides the e-Design process
- The system and technical views of the acquisition process map into the e-Design system architecture
- The e-Design service-oriented architecture maps into the distributed GIG system

CENTER FOR e-DESIGN

© Copyright 2002-

Sample Partners of the Center

INDUSTRIAL

GE
Ford
ALCOA
LOCKHEED MARTIN
RESPIRONICS
Raytheon
ANSYS INCORPORATED
BAE SYSTEMS
PTC
Pratt & Whitney A United Technologies Company
IBM

FEDERAL

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA
NASA
NIST National Institute of Standards and Technology
NSF

ACADEMIC

UNIVERSITY OF PITTSBURGH
Carnegie Mellon
UMASS.

© Copyright 2002-

CENTER FOR e-DESIGN

Thank you!

Questions?

© Copyright 2002-